Experiments of Particle-Concentration Variability and Transport Associated with Turbulent and Convective Processes

Jeffrey D. Parsons
University of Washington, School of Oceanography, Seattle WA 98195-7940
phone: (206) 221-6627, fax: (206) 616-1247, email: parsons@ocean.washington.edu

Award Number: N000140310138
http://www.ocean.washington.edu/people/faculty/parsons/research/cs.html

LONG-TERM GOALS

To understand the mechanics of small-scale sediment-fluid interactions and how these processes affect transport and deposition of terrestrial material on active continental margins. Convective sedimentation (CS) and preferential concentration (PC) are two newly formulated processes that have the potential to change the way we think about delivery of riverine material to the continental shelf and beyond.

OBJECTIVES

- To analyze and publish the results of preliminary experiments, which found CS and PC in sediment-laden mixed layers.
- To formulate an empirical model that can predict sediment scavenging (i.e., effective removal rates) from stratified river plumes.
- To construct a facility capable of producing a stratified, sediment-laden mixed layer similar in both character and size as natural river plumes.
- To perform a series of experiments varying the inlet condition (and other variables) to identify the concentration required to produce a hyperpycnal flow.
- To use prototype equipment (developed in conjunction with a NSF-MRI grant) to attempt to identify the presence of PC and identify its role in particle settling in natural-scale turbulent shear layers.
- To develop predictive models of particle-concentration and sorting associated with the interaction of CS and PC.

APPROACH

Using a variety of instrumentation, we have sought to identify the environmental variables regulating the transport of sediment from the water column by turbulent, convective means. We rely heavily on laboratory experiments to constrain theoretical models. The experiments have thus far focused on the flow of a steady flow of fresh, sediment-laden fluid above a clear brine contained within a confined basin. The experiments have also provided an ideal testing ground for new field instrumentation (e.g.,

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14. ABSTRACT
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the FOBS-7 produced by D&A Instruments). Because the phenomena we intend to study have not been observed directly in the field (mostly due to instrumentation limitations), we will continue to develop new techniques that will enable measurements of these important, complex processes in natural settings.

WORK COMPLETED

- Identified the dimensionless variable regulating mixing-induced convective sedimentation common in laboratory experiments and related it to the dimensionless vertical flux (Figure 1a).

- Used the scaling relationship discovered to accurately predict vertical fluxes measured during STRATAFORM (Figure 1b).

- Incorporated these results into a STRATAFORM Master Volume chapter (Parsons et al., in revision) and a chapter of The Sea (Chapter 17: Parsons and Nittrouer, 2004).

- Constructed a laboratory facility that is able to produce of comparable scale to natural surface river plumes (Figure 2).

- Performed an initial calibration of the facility.

- Begun to test the limits of the model formulated by McCool and Parsons (2004), both with respect to scale and ambient stratification.

RESULTS

We have established that suspensions can organize themselves to rapidly deposit material at riverine sediment concentrations commonly measured on tectonically active margins (i.e., 300-1000 mg/l). Through the use of dimensional analysis and an exhaustive set of experiments, we have identified a scaling relationship, which collapses the laboratory data (Figure 1a; McCool and Parsons, 2004). We have used this relationship to successfully predict effective settling rates observed on the Eel River margin during the STRATAFORM program (Figure 1b; McCool and Parsons, 2004). The concentrations examined in this course of experiments were also substantially less than what has been known to initiate CS in the past (10 g/l: Maxworthy, 1999; 1 g/l: Parsons et al., 2001).

Construction of the new facility was delayed for several reasons, most notably a renovation of our lab space. Despite the delays, the facility is complete and operational (Figure 2). Preliminary experiments testing the operational limits of the facility are currently being performed. During the delays, we have focused on the earlier results and their application to extreme events occurring on continental margins (Parsons and Nittrouer, 2004; Parsons et al., in revision).

IMPACT/APPLICATIONS

The discovery of convective transport processes in turbulent fluids at concentrations less 1 g/l represents a significant scientific finding. Most rivers (even benign, passive-margin rivers) produce these concentrations during floods. Though mouth geometry and tidal characteristics may diminish the prevalence of CS in low-energy (passive-margin) rivers, there are numerous situations where conditions will be favorable for this transport mode, particularly when considering ancient environments. For instance, modern low-latitude rivers produce ~1 g/l consistently and for long durations. In these systems, distribution of material is most likely controlled by the intereaction of CS with large-scale currents (e.g., Papua New Guinea: Kineke et al., 2000). Wet, temperate, unadulterated watersheds may also represent an environment affected by CS and PC, though ultimate deposition may be regulated by other hydrographic processes (e.g., Parsons et al., 2004; Puig et al., 2004).

The empirical relationships based upon the laboratory experiments and scaling analyses provide numerical modelers with the capability of integrating small-scale particle-turbulence interactions into their models. Ongoing collaboration with Courtney Harris and her implementation of a Regional Ocean Model System (ROMS) in conjunction with workers at SCALANT.

TRANSITIONS

We believe that the simple CS models we are developing will be used in conjunction with the margin models being developed to predict margin morphology and stratigraphy (e.g., Syvitski and Hutton, 2001; Kassem and Imran, 2001). Our results should help guide observations made by other field workers outside of EuroSTRATAFORM and enable them to develop strategies for the observation of sediment-concentration variability and particulate transport in natural systems.

RELATED PROJECTS

This project is closely related to experiments investigating the interactions of surface gravity waves and high-density, near-bed suspensions. The first set of experiments is in the last stage of publication (Lamb et al., in press; Lamb and Parsons, pending acceptance). The experiments validated the thought experiment posed by Wright et al. (2001). Their idea was that a critical Richardson number exists within the wave boundary layer such that the relatively uniform concentration within it is set by the square of the orbital velocity. However, sorting within the near-bed layer and the spatial distribution of turbulence production were much more complex than previously thought. These led to the effective critical Richardson number being substantially smaller than posed originally by Wright et al. (2001). The next set of experiments, which will investigate high-density suspensions in the absence of sandy material, has begun under the direction of Dr. Hannah Liang. Details about these experiments and associated fieldwork in ancient rocks can be found at:

http://www.ocean.washington.edu/people/faculty/parsons/research.

The simplified models produced from our results will be used in conjunction with numerical models produced by Jasim Imran and James Syvitski, for ultimate use in ***Sedflux***. We also have an ongoing collaboration with Courtney Harris to work on ways to implement the formulations we have posed in her ROMS model.

An NSF Major Research Instrumentation project (with Andrea Ogston) specifically addresses the needs of both laboratory and field instrumentation. As a part of this project, we are constructing a probe that can measure an array of points in the water column (~ 20), each with an extremely small sampling volume (e.g., 1 cm^3). The probe is complete and is being integrated into the upcoming experiments in the river-plume flume.

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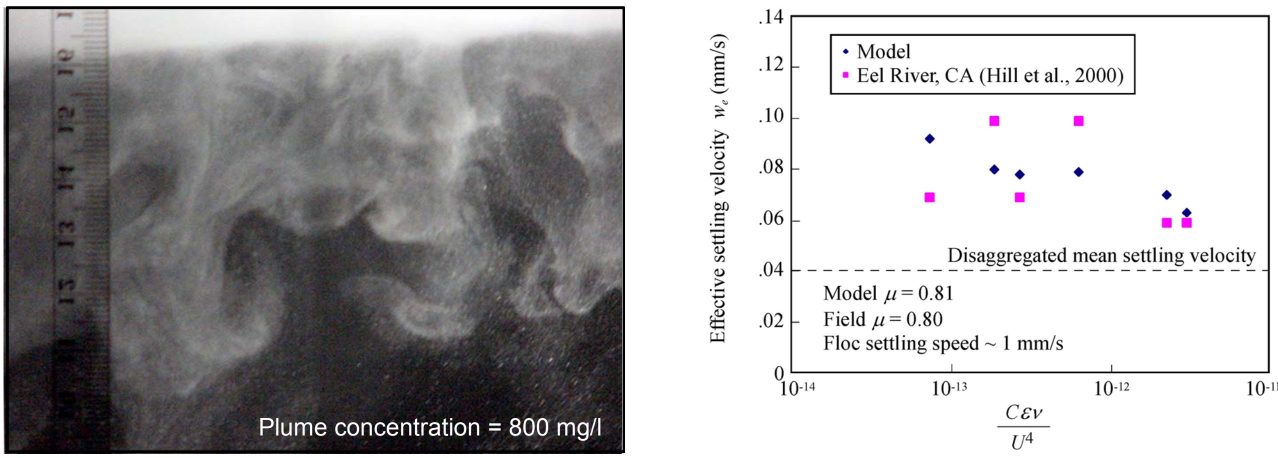

Figure 1a) Left: Photograph of convective sedimentation in an experiment where the sediment concentration above the mixed layer was 800 mg/l. b) Right: Comparison of our proposed relation (model) with data obtained from the Eel River margin during STRATAFORM (Hill et al., 2000). As noted in the figure, effective settling rates were not well predicted by individual floc or disaggregated settling speeds.

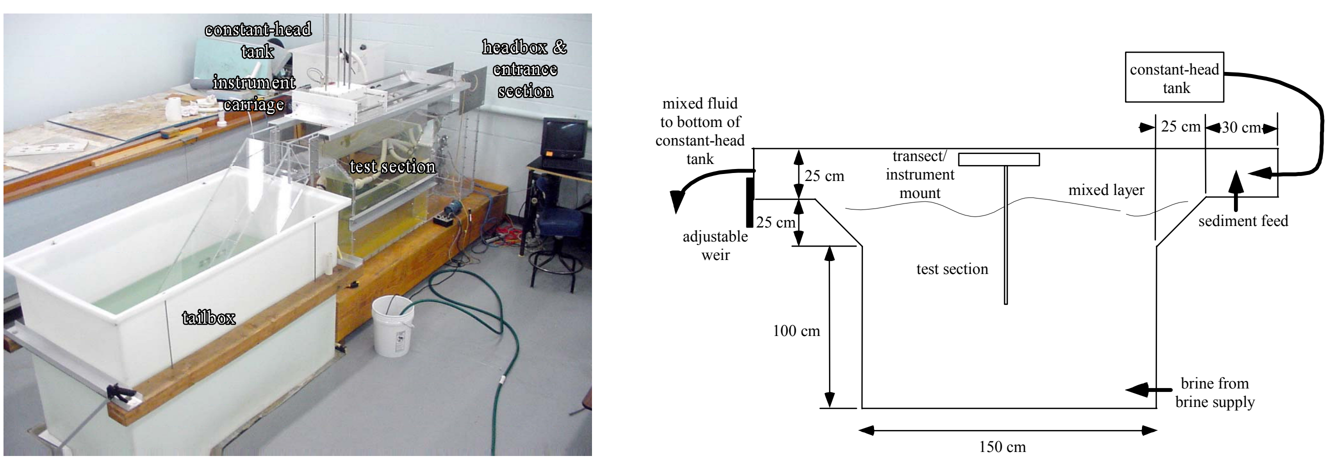

Figure 2a) Left: Photograph of the river-plume flume. b) Right: Schematic of river-plume flume. The fresh, sediment-laden fluid is supplied from a constant-head and sediment input. This arrangement minimizes the influence of pump turbulence and produces a realistic boundary-layer flow at the point where the saline basin is encountered.